Ground Water Induced Flooding in the Bellevue Ohio Area Spring and Summer 2008

ODNR—Division of Water

James Raab, Bill Haiker, and Wayne Jones

and

ODNR—Division of Geological Survey

Michael Angle, Rick Pavey, Mac Swinford, and Donovan Powers

ODNR Division of Water Technical Report of Investigation 2009-1

January 2009

OHIO DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

SOIL & WATER CONSERVATION
Ohio Department of Natural Resources

O.D.N.R
GEOLOGICAL SURVEY

CONTENTS

FIGURES

TABLE

APPENDICES

Ground Water Induced Flooding in the Bellevue Ohio Area Spring and Summer 2008

INTRODUCTION

On March 18, 2008 ground water levels rose to 40-year-high levels in the Bellevue, Ohio area. Sinkholes, rounded depressions in the landscape formed by solution of bedrock or collapse of an underlying cavity, which typically accept surface water, were acting as springs. Flooding of fields, roadways and homes occurred because of the lack of a defined surface drainage. The purpose of this report is to outline the geologic, hydrologic, and meteorological conditions that led to the flooding experienced in the vicinity of Bellevue, Ohio in the spring and summer of 2008. Figure 1 is a map showing the areas that experienced flooding. A combination of geologic conditions present at the surface and near-surface, and unique increases in precipitation, created a situation where a rising ground water table breached the ground surface, flowed from existing sinkholes, filled existing closed basins and karst features, and drained slowly over the course of months.

SUMMARY OF HYDROLOGIC CONDITIONS

Unlike most flooding events caused by surface water runoff, the flooding that occurred in and north of Bellevue in the spring and summer of 2008 was caused by excessive ground water upwelling through near-surface openings in the underlying limestone bedrock. Although this phenomenon is common to the north of this area as represented by the perpetual flow from the "blue holes", flooding due to upwelling ground water in the area in close proximity to Bellevue has happened only six times since 1800. The last two occurrences prior to 2008 were in 1969 and 1937. All three of these occasions were in response to heavy precipitation events.

Ground water supplies are replenished by precipitation; especially by the rain and snow that falls from November through April, a period referred to as the ground water recharge season. Record and near-record amounts of rain had fallen throughout much of Ohio during the recharge season of 2008. Cumulative precipitation from October 2007 through March 2008 in the North Central climatic region of Ohio, which includes the Bellevue area, had totaled a record 23.55 inches, 9.14 inches above normal (Kirk, 2008). This surpassed the previous record of 21.56 inches set in 1898. Ending this wet period was near-record precipitation that fell in March, averaging 5.41 inches for the north-central region, making it the third wettest March in the past 114 years. Much of this precipitation fell as snow and did not melt until mid-month. Due to the karst geology in this area, much of this surface water flowed into the sinkholes causing the ground water levels to rise.

GENERAL GEOLOGY

The Bellevue area surface and near-surface geology is unique, creating a situation which allowed the unusual karst flooding to occur in a localized area. Beneath the city of Bellevue and areas to the north and south of the city is a six- mile-wide band of limestone bedrock, the Delaware and Columbus Formations (denoted as Dc and Dd on Figure 2). This band trends in a generally north-south direction from Lake Erie through Central Ohio. The Olentangy Shale (Do) and Ohio Shale (Doh) are younger bedrock formations that overly the Delaware Limestone to the east. The Salina Dolomite (Ss) underlies the Columbus Limestone and is present at the surface to the west. Contacts between the bedrock units generally run north and south because of the gentle eastward tilting of the bedrock units as they descend into the Appalachian Basin to the east. Figure 2 is a bedrock geology map of north central Ohio.

The Columbus Limestone, and to a lesser extent, the Delaware Limestone are prone to the formation of sinkholes, caves, and caverns (collectively called karst) due to the dissolution of the high-calcium, generally coarsely crystalline nature of the rock. Slightly acidic ground water flowing through pore and fracture spaces in these formations dissolve the limestone and result in the numerous karst features in this localized area. Collapse of more competent limestone above the solutioned zones has formed some of the caves and caverns in this area. Seneca Caverns, the largest cavern in northern Ohio, was formed in this manner. Appendix A shows a typical progression in the development of karst geology. The Olentangy Shale and Ohio Shale to the east are not prone to the formation of karst. Thus, karst features abruptly stop near the interpreted contact with the Delaware Limestone and the overlying Olentangy/Ohio Shale. Figure 3 shows the area prone to karst features. To the west, the Salina Dolomite is near the surface, but dolomite (chemical composition of $Mg\ Ca\ CO_3$) is less prone to dissolution than limestone (chemical composition of $Ca\ CO_3$) and therefore karst formation is less frequent or developed.

The glacial geology of the area also contributes to the development of karst in the Bellevue region. Ice Age glaciers covered north central Ohio on several occasions and commonly deposited 50 or more feet of clay-rich glacial till. However, in the Bellevue area the thickness of the glacial drift is commonly less than 20 feet or not present at all. The lack of glacial till allows

Figure 1.—Location map of the study area..

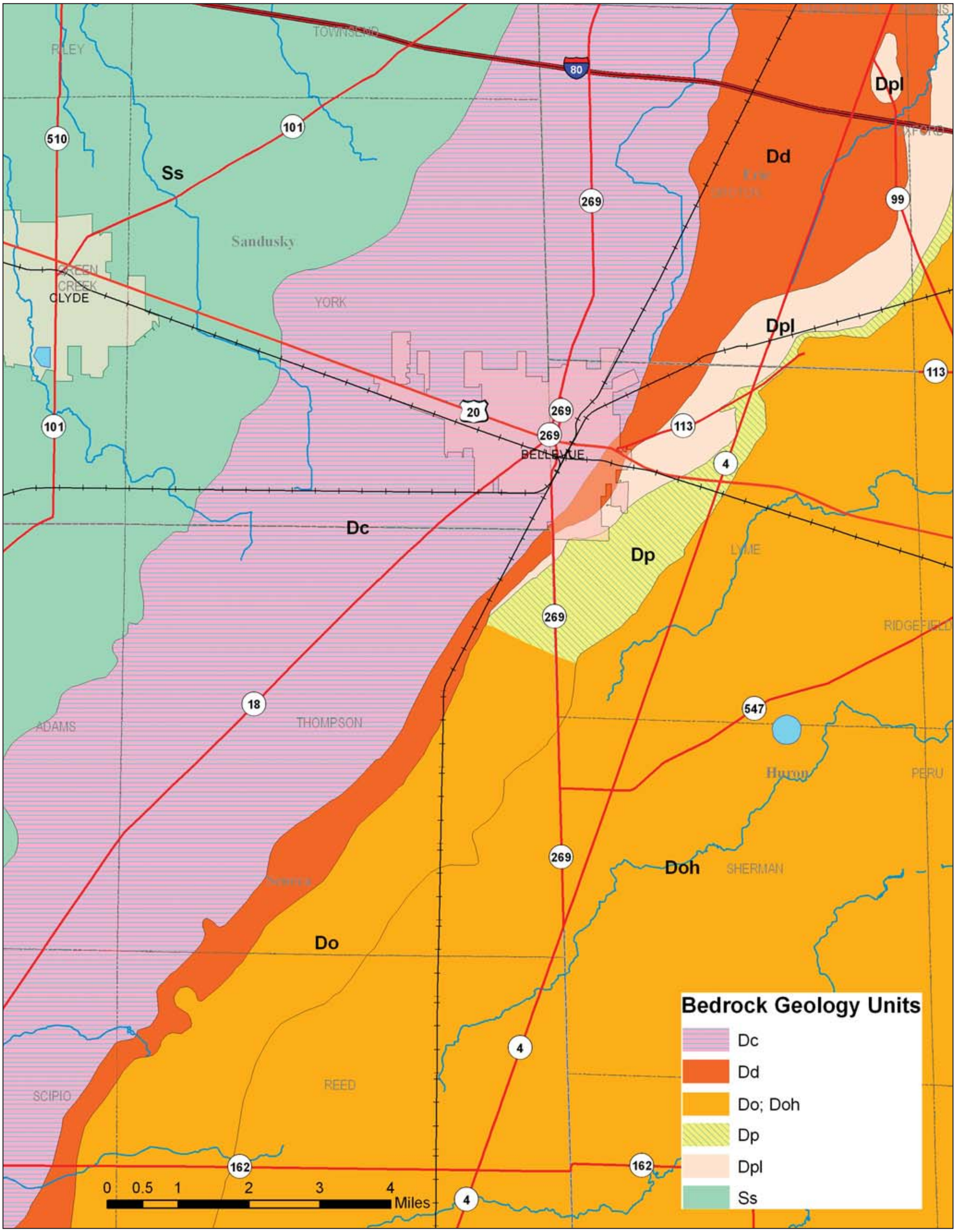

Figure 2.—Bedrock geology of north central Ohio. **Dc**-Columbus Limestone, **Dd**-Delaware Limestone, **Do**-Olentangy Shale, **Doh**-Ohio Shale, **Dp**-Prout Limestone, **Dpl**-Plum Brook Shale, **Ss**-Salina Group. Modified from Bedrock Geologic Map of Ohio, Slucher, E.R., et al.

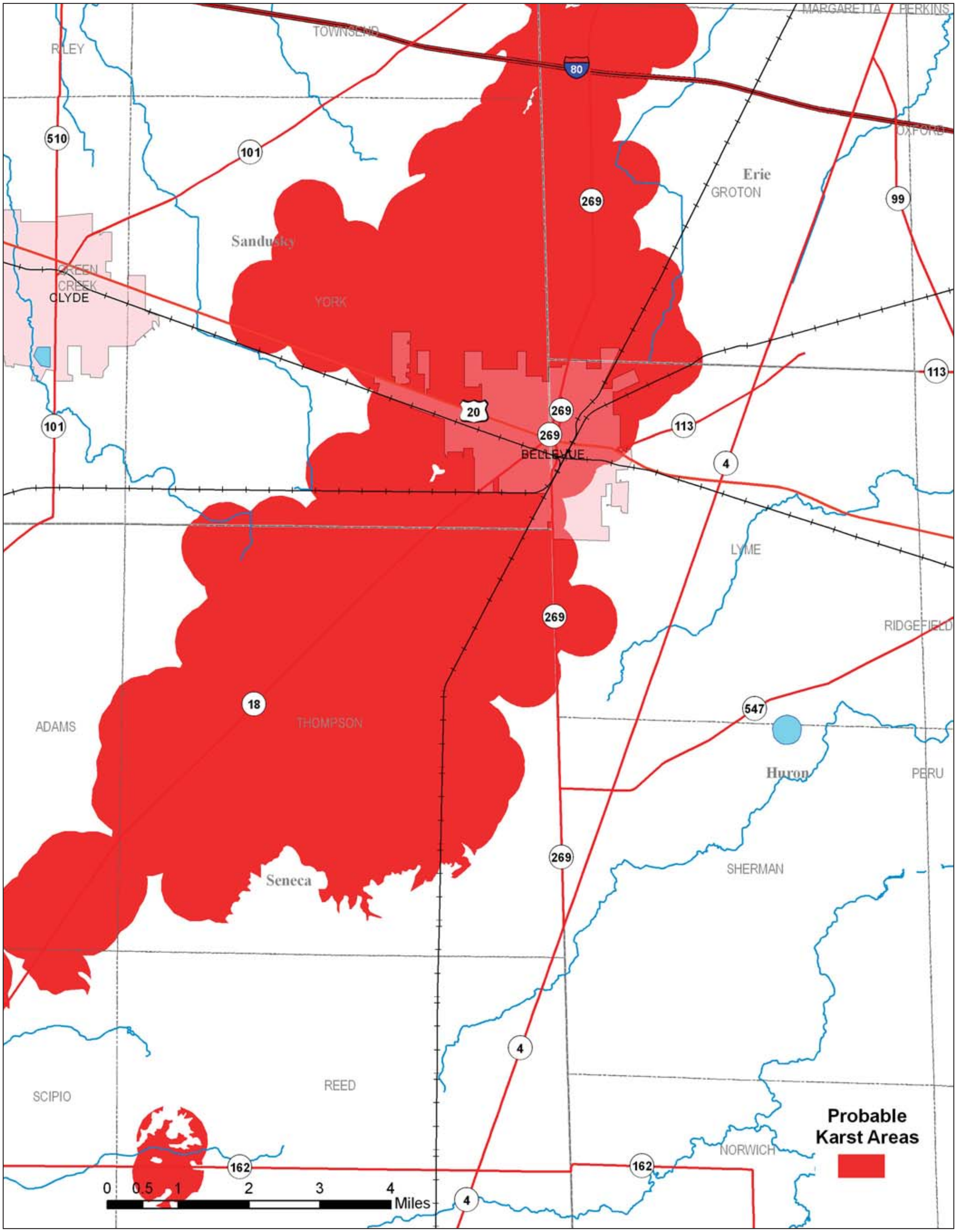

Figure 3.—Karst areas in north central Ohio. Modified from Known and Probable Karst, Pavey, R. et al.

the surface water direct contact with underlying limestone and provides more opportunity for dissolution. The drift thickness map (figure 4) shows the approximate areas of less than 20 feet of glacial drift. Karst is generally best developed where thin drift overlies the Delaware and Columbus Limestones. One potential reason for the thinner glacial drift in the vicinity of Bellevue is that the Columbus Limestone was resistant to erosion and formed a ridge that impeded glacial erosion and minimized deposition. Another cause is that the Bellevue area was inundated by waters of Lake Maumee and other ancestral lakes, and wave erosion from these lakes stripped much of the previously deposited drift away. Prominent sandy beach ridges associated with these ancestral lakes are visible just to the west of Bellevue and Castalia. The Columbus and Delaware Limestones are subject to dissolution where highly permeable sandy beach ridges overlie these units and thick clay deposits are absent. Thicker drift deposits covering the Delaware and Columbus Limestones probably protected the units from contact with significant amounts of surface water, preventing initiation of large dissolution features. Other regions of the state that have well-developed karst features, such as along the Scioto River in Delaware and Franklin Counties, and portions of Highland and Adams Counties, occur in limestone and dolomite units in areas of thin glacial drift or areas in which glacial drift is absent.

Joints (breaks in rock along which no movement has occurred) are found throughout the local bedrock formations. Regionally, the joints in bedrock generally trend NE-SW and NW-SE and are natural pathways for ground water to flow within the rock formations. These narrow joints are widened through the dissolution of the limestone by the surface and ground water that flows though them, leading to the eventual widening of the joints into a pathway. The northeast-southwest trending joints play a particularly important role in the travel of ground water in the Bellevue area and are crucial to understanding the karst flooding along the trend.

The relationship between these joint patterns and sinkholes is complex and variable. Two adjacent sinkholes may or may not be interconnected by joints. Water will preferentially flow along certain joint patterns. The net result is that different sinkholes are able to accept water at different rates, and in reverse may "flood" areas with different intensities if hydraulic pressures build up like they did in the spring 2008.

GROUND WATER LEVEL RESPONSE TO HEAVY PRECIPITATION

The presence of over 1000 sinkholes in Thompson, York, Lyme, and Groton Townships allow surface water to flow directly into the ground water system. Surface runoff flows into these sinkholes. With no soil present to act as a filter, millions of gallons of water were able to flow into the ground water system over a short period of time, causing a quick rise in the water table level. Sinkholes located north of Bellevue that typically accepted water became springs because the water table had risen above land surface.

A 1992 ground water study conducted by the ODNR - Division of Water (DOW) determined that ground water levels in Thompson Township of Seneca County had risen 27 feet in four days in response to receiving less than 3 inches of rain (ODNR, 1994). After 17 days, the water table had declined only 14 feet. Another storm later that same year dropped approximately 5 inches of rain over a six day period. Ground water levels increased almost 50 feet in three days. After one month of intermittent rains, the ground water level was still 30 feet higher than before the initial 5-inch rainfall event. It would take approximately 70 days to return to pre-storm level if little to no precipitation occurred.

Dick Bell, owner of the Seneca Caverns, noted that on April 1, 2008; the ground water level at the Caverns was approximately 35 feet below land surface (pers. comm., 2008). By July 28, the ground water level had dropped approximately 47 feet or to 82 feet below land surface. This translates to an average rate of decline in the aquifer of 0.4 foot/day. Mr. Bell noted that during dry times the water table dropped 8-12 inches/day but after different rainfall events, the water table stabilized for one to two days at a time.

Spring discharge data has been collected by personnel at the Rockwell Springs Trout Club. This spring is located near the intersection of County Roads 310 and 247 in Sandusky County and is down-gradient of the flooded areas. Data for the past 18 years was sent to the DOW. This spring is very responsive to precipitation events, which indicates that it is connected to the shallow ground water flow system. Data for 2007 and 2008 shows that the spring discharge was slightly above normal starting in December 2007, but then peaked the third week of March, more than doubling the average flow for that time period (see Figure 5). Spring discharge stayed above average until the third week of August.

The DOW has been in the process of mapping the potentiometric surface within the aquifers in Ohio. These maps, which use existing water well record data, show the direction and gradient of ground water flow. By using these maps, the ground water capture zone for the flooded areas in York and Groton Townships was determined to be approximately 57,000 acres in size. Figure 6 shows the approximate ground water recharge area that contributed to the flooding. This area encompasses most of Thompson Township and portions of Reed, York, Lyme and Groton Townships. Most of this area, especially Thompson and York Townships, has minimal surface drainage because of the high concentration of sinkholes. Ground water recharge is

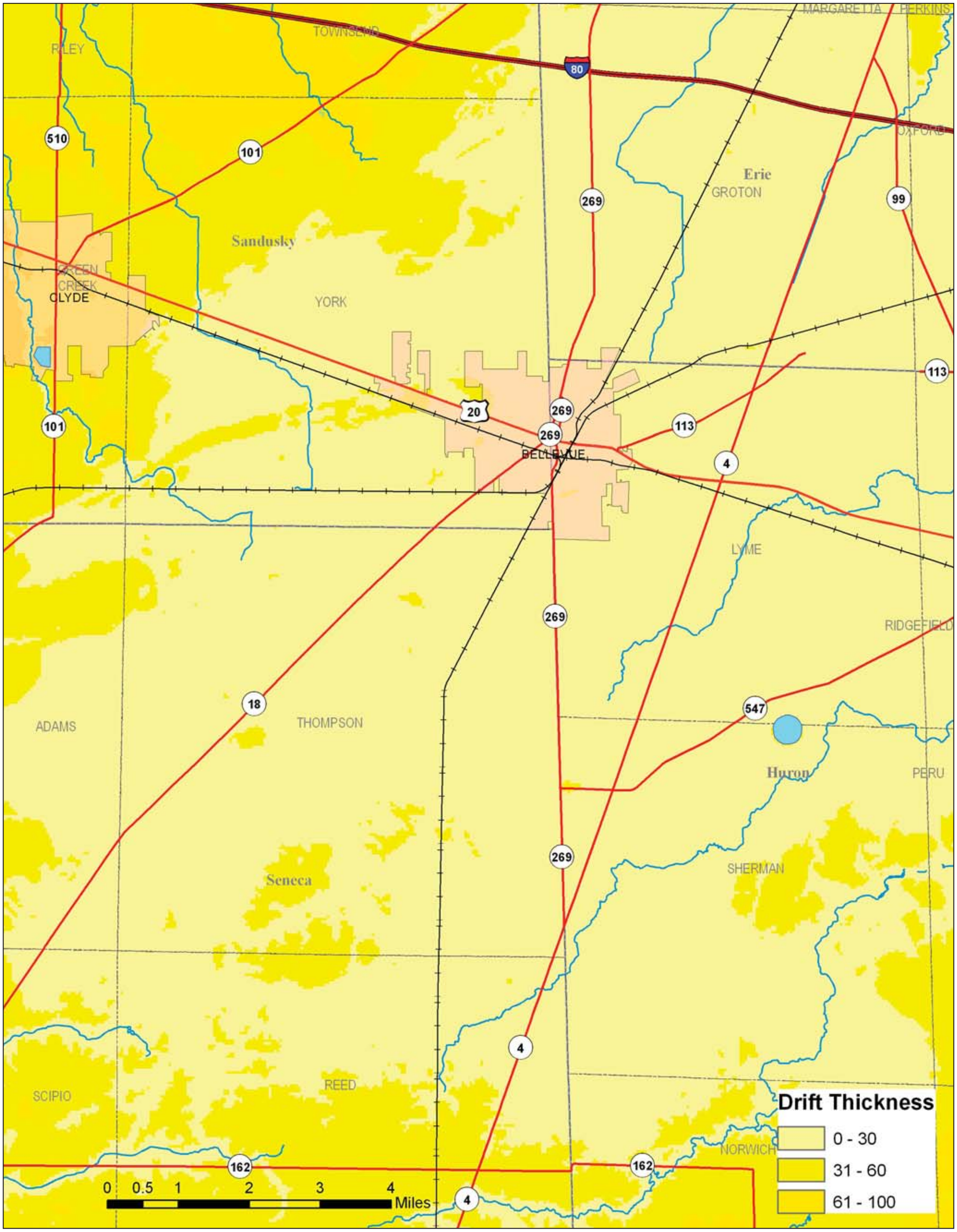

Figure 4.—Drift thickness map of north central Ohio. Drift thickness is measured in feet. Modified from Shaded Drift Thickness of Ohio, Powers, D.M. and E.M. Swinford.

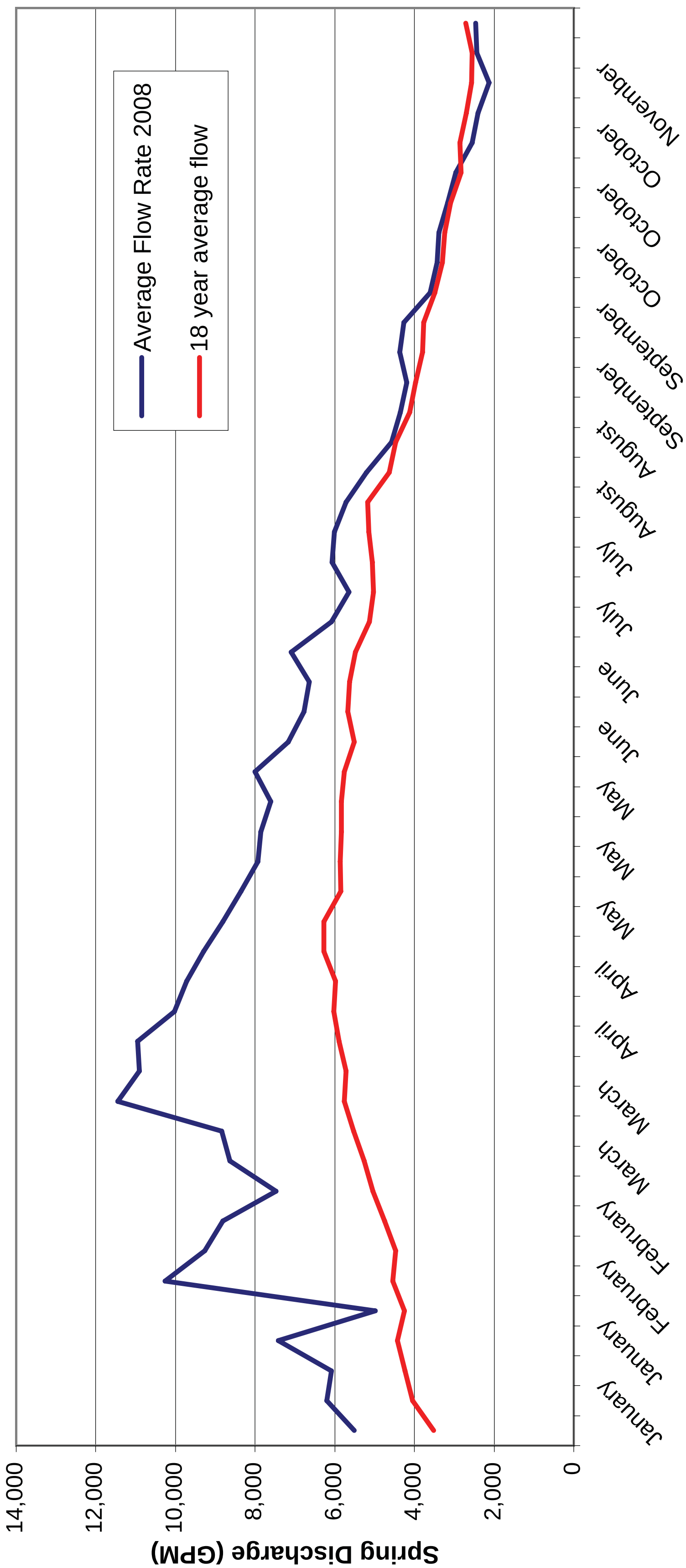

Figure 5.—Spring discharge from Rockwell Springs Trout Club

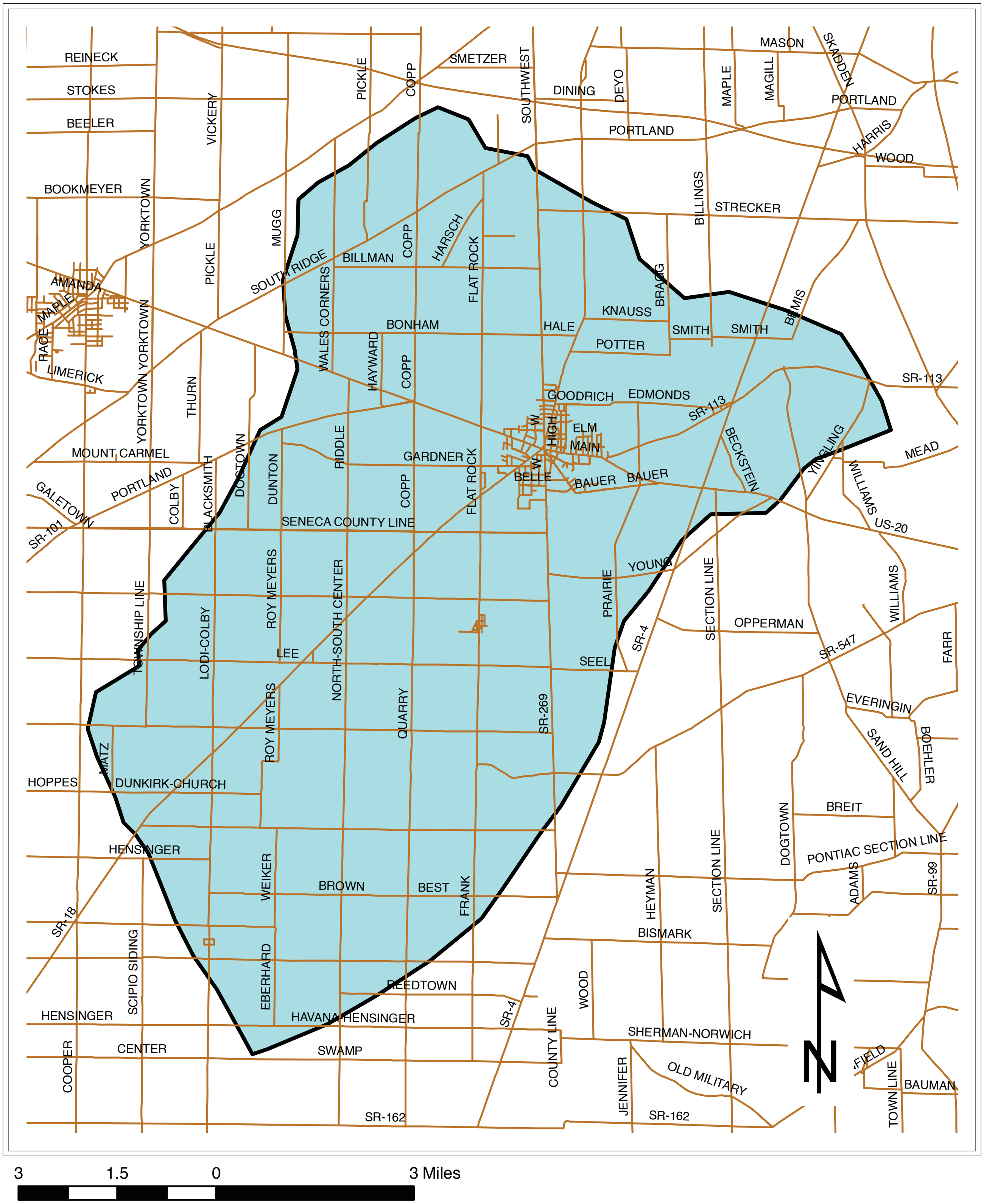

Figure 6.—Ground water contribution zone for the flooded areas.

almost instantaneous in these areas as surface water enters the sinkholes. Assuming 30% of the precipitation that falls within the capture zone drains into the sinkholes and thus the aquifer, of the 5.41 inches that fell during March 2008, approximately 2.5 billion gallons recharged the aquifer. Since the air temperature was fairly cool in March and evapotranspiration was low, the amount of precipitation that entered the ground water system could have been higher.

SYNOPTIC GROUND WATER LEVEL SURVEY

On September 3, and October 22, 2008, personnel from the DOW measured the depth to water in 26 water wells in the area north and west of Bellevue, Ohio. This area lies within both Sandusky and Erie Counties. This is the area that experienced the most severe ground water flooding during the spring and summer 2008. The purpose of the study was to record synoptic ground water levels and to document the changes in the water table in the limestone aquifer.

Table 1 shows the data that was collected in addition to the existing information obtained from the water well records on file with the DOW. The original static is the depth from land surface to the water table as measured by the driller when the well was installed. The M Static 9/3/08 and M Static 10/22/2008 columns record the depth to water measured by DOW personnel on those dates. The Water Level Difference column is the difference between the October 22 static water level and the September 3 static water level. A negative number indicates that the ground water level was higher on September 3 than on October 22, 2008. All but two wells had a higher ground water level on September 3rd than on October 22nd.. The average decline in ground water levels over this 49 day period was approximately 7 feet. This translates to a decline in ground water levels of approximately 2 inches/day. Using flood elevation data collected by the Erie County Engineer's Office as a high ground water level mark, ground water levels have declined 45-50 feet in the heaviest hit areas since the end of March. This is equivalent to a decline in the ground water levels of approximately 3 inches/day. Of the 26 wells that were measured, the average depth to water was within one foot of the average static water level measured when these wells were drilled. This indicates that ground water levels had returned to near-normal conditions by the end of October.

Contour maps were created using the data from both synoptic water level surveys (see Figures 7 and 8). These maps show the locations of the wells that were measured along with the corresponding elevation of the water table that was measured. This data was contoured using a 10-foot contour interval. Ground water flows from areas of high elevation to areas of lower elevation, in a direction perpendicular to the contour lines. From Figures 7 and 8, it shows that ground water flows from the west, south and east into the area that experienced the worst flooding. Synoptic water level data collected in Thompson Township in the early 1990's also support this finding (ODNR, 1994). The orientation of this ground water low coincides with the orientation of the major joint trend observed in the Columbus Limestone.

A contour map was created that shows the change in ground water over this 49-day period (see Figure 9). There is a band of wells that measured greater than a 10-foot decline. This band trends in a northeast direction and coincides with the center of the ground water basin. This is the area that experienced the most prolonged flooding. The well located at the corner of State Route 269 and Portland Road shows a much higher static water level elevation. After examination of the water well record, it appears that this well did not intercept any cavities or fractures. The original test rate was 8 gallons per minute (gpm) with total drawdown after one hour. Wells that encounter fractures or cavities can be pumped at rates exceeding 100 gpm (Walker, 1986). The well located on Deyo Road that was measured in this study shows similar ground water fluctuations. The characteristics of these two wells indicate that these wells do not intercept any major fractures or cavity zones. Ground water flow to these two wells is through primary porosity.

CONCLUSIONS AND RECOMMENDATIONS

The extent and duration of flooding that was experienced in and north of Bellevue during the spring and summer 2008 was not the typical sporadic surface flooding of a few sinkhole basins. The flooding during this time period was due to the ground water levels rising above ground level in many sinkhole basins. Record October 2007 to March 2008 precipitation levels, culminating with 5.41 inches of rain in March, added billions of gallons of water into the aquifer. The last two times this type of flooding has occurred in this area were in 1969 and 1937.

The formations present in this area that are favorable for karst development are the Columbus Limestone and to a lesser degree the Delaware Limestone. These limestones outcrop in a six-mile-wide band that trends almost north-south. The thin-to-absent glacial drift over these limestones makes the Bellevue area prime for karst development. Regionally, the joints in bedrock generally trend NE-SW and NW-SE and are natural pathways for ground water to flow within the rock formations.

The presence of over 1000 sinkholes in the Bellevue area allows surface water to rapidly flow directly into the ground water system. Ground water levels were not measured in the Bellevue area prior to the flooding. However, ground water levels measured in a previous study showed that ground water levels can rise up to 50 feet over a few day period in response to five

Table 1.—Synoptic ground water level data collected in the Bellevue, Ohio area

Address	Latitude (degrees)	Longitude (degrees)	M Static 9/3/2008	M Static 10/22/2008	Original Static (feet)	Depth (feet)	Elevation (feet msl)	Water Level Elevation 9/3/2008	Water Level Elevation 10/22/2008	Water Level Difference 9/3 to 10/22
530 CR 308	41.33044	-82.85929	64	72.12	65	142	725.9	661.90	653.78	-8.12
938 CR 308	41.3184	-82.85939	64.89	74.92	70	140	737.3	672.41	662.38	-10.03
1260 CR 308	41.30879	-82.86102	25.63	31.51	60	125	726.1	700.47	694.59	-5.88
468 CR 294	41.33752	-82.89548	47.73	50.7	56	114	689.9	642.17	639.2	-2.97
1002 CR 302	41.31808	-82.8789	41.3	50.82	30	103	735	693.70	684.18	-9.52
1929 CR 302	41.29004	-82.87844	57.98	71.09	79	145	750	692.02	678.91	-13.11
2588 CR 302	41.27065	-82.87902	80.88	94.77	80	150	780	699.12	685.23	-13.89
2104 CR 292	41.28443	-82.8985	29.85	36.06	60	115	763.5	733.65	727.44	-6.21
2636 CR 292	41.26962	-82.89841	22.52	37.56	60	80	776.1	753.58	738.54	-15.04
6416 Kilroy	41.35952	-82.82903	52.49	57.59	86	125	700.47	647.98	642.88	-5.1
7219 Deyo	41.35026	-82.81739	20.05	20.35	30	103	712.8	692.75	692.45	-0.3
11801 Strecker	41.32899	-82.82743	42.7	53.23	56	84	711.3	668.60	658.07	-10.53
12314 Strecker	41.32172	-82.83894	52.1	63.91	65	90	720	667.90	656.09	-11.81
9208 Bragg	41.32244	-82.80443	35.02	37.33	25	100	714.4	679.38	677.07	-2.31
6906 SR 269	41.3534	-82.82991	41.52	46.87	80	105	684.1	642.58	637.23	-5.35
7706 SR 269	41.34251	-82.83005	21.09	19.78	13	105	735	713.91	715.22	1.31
8906 SR 269	41.32564	-82.82939	41.17	51.51	48	103	709.9	668.73	658.39	-10.34
10318 SR 269	41.30565	-82.8286	37.5	50.36	50	110	718.04	680.54	667.68	-12.86
400 S. CR 312	41.33457	-82.84576	91.05	98.79	70	130	750	658.95	651.21	-7.74
10318 SR 269 Monitor	41.30518	-82.82762	30.6	43.56	12.8	150	717.6	687.00	674.04	-12.96
12416 Dining	41.35078	-82.84128	45.33	50.99	49	100	697.35	652.02	646.36	-5.66
Cunningham Monitor	41.33749	-82.80006	38.98	40.03	30.5	150	710.2	671.22	670.17	-1.05
Keller Monitor	41.33985	-82.76007	22.54	20.9	19.85	150	715	692.46	694.1	1.64
Young Monitor	41.31853	-82.77008	29.16	29.62	21.2	150	720	690.84	690.38	-0.46
10817 Billings	41.30137	-82.79293	41.31	46.07	27.4	150	730	688.69	683.93	-4.76
9102 Rogers	41.37185	-82.84366	45.34	48.97	45	100	685	639.66	636.03	-3.63

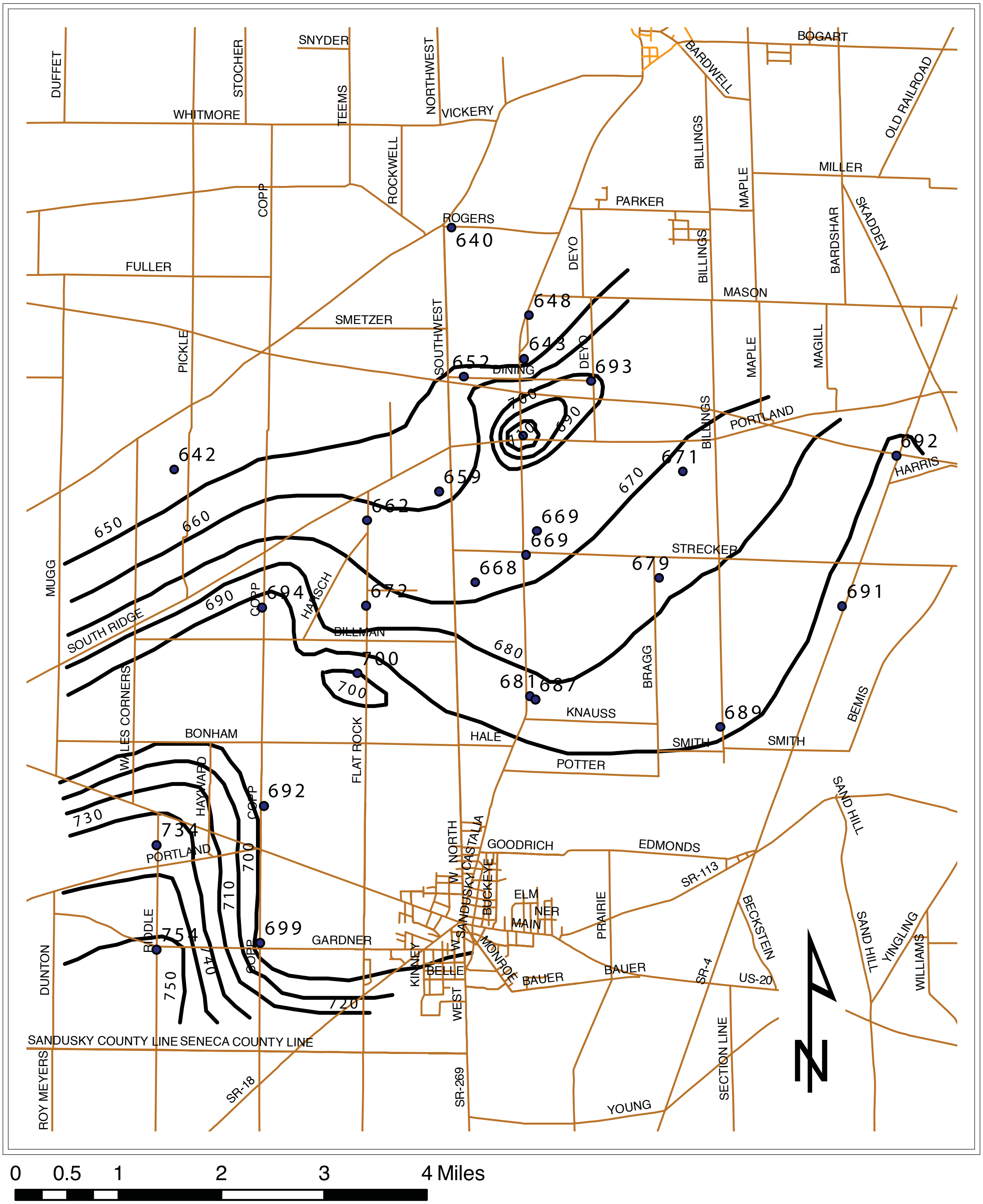

Figure 7.—Water table map of the Bellevue area as measured on September 3, 2008.

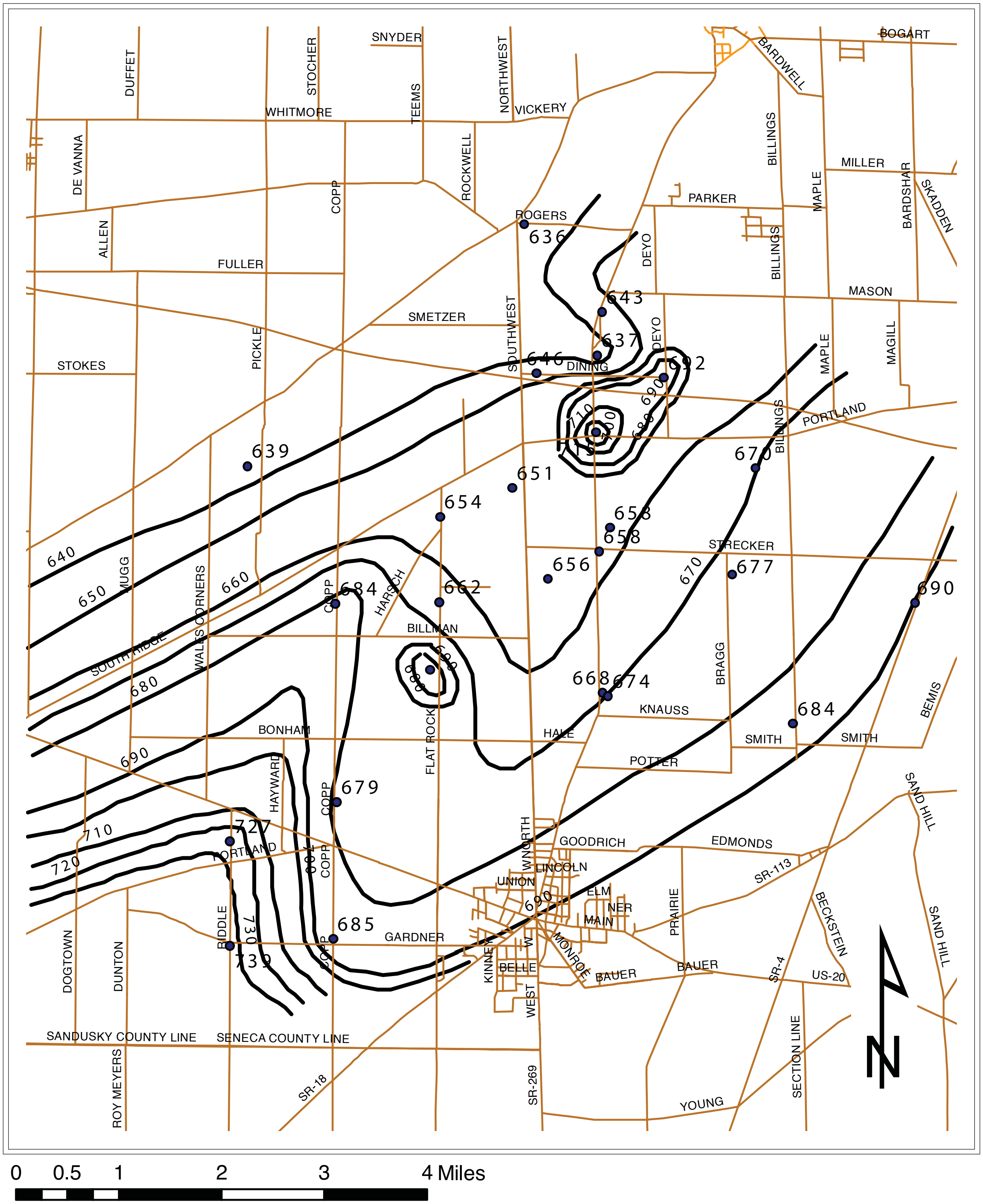

Figure 8.—Water table map of the Bellevue area as measured on October 22, 2008.

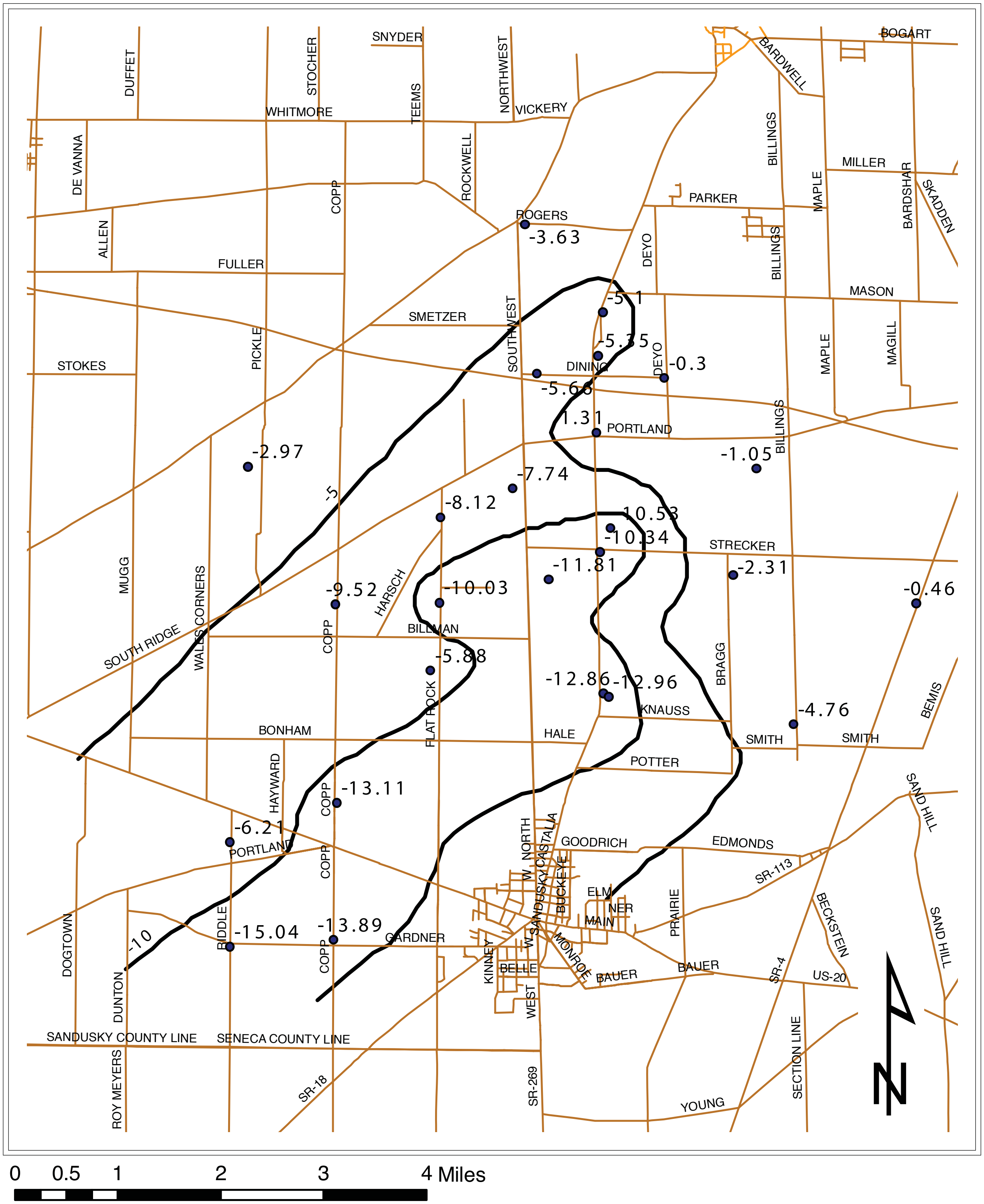

Figure 9.—Water level difference map.

inches of rain, but take weeks to return to pre-flood conditions. Ground water levels at Seneca Caverns declined on average 4 inches/day and had dropped approximately 65 feet from April 1 to October 22, 2008. Ground water levels measured in October 2008 by DOW staff indicate that the water table has declined 45 to 50 feet north of Bellevue since the spring 2008. This equates to a 3 inches/day decline.

The approximate size of the ground water watershed that contributed water to the flooded karst area is 57,000 acres. This area encompasses most of Thompson Township and portions of Reed, York, Lyme and Groton Townships. Synoptic ground water level surveys conducted in the fall 2008 indicate that there is a ground water low area. This low parallels the major joint orientation measured in the Columbus limestone and lies beneath the area that experienced the worst flooding.

This document along with figures and maps can be used as an historic document, so that steps can be taken to avoid property damage when flooding occurs again. Local government agencies should consider mandating no permanent structures within the areas that flooded and recommend no basements in structures located adjacent to these areas.

Best management practices, such as sinkhole structures and grassed buffer strips and waterways should be implemented around sinkholes to minimize ground water contamination and to keep the sinkholes open to prevent surface flooding.

Even though ground water levels have returned to normal levels, two or three wells completed in the karst zone should be regularly monitored to get a better understanding of how ground water levels change in response to precipitation events. The monitor well located at 10318 State Route 269 could be used as one of these wells. Other monitor locations would be southwest of this well. Equipping these wells with pressure transducers that record ground water levels multiple times per day would lead to a better understanding of the dynamic nature of the karst aquifer system.

During the time of the flooding, a Frequently Asked Questions fact sheet was put together by the DOW. Since then a few other questions were raised. Appendix B is a list of frequently asked questions with responses from DOW personnel.

REFERENCES

Bell, Dick, personal communication, 2008.

Ohio Department of Natural Resources, Division of Water, Seneca County SWCD, L. Drane, and R. Kocher, 1994, Impact of Best Management Practices on Surface Runoff and Ground Water Quality in a Solutioned Limestone Area, Thompson Township, Seneca County, Ohio, 54 pp.

Monthly Water Inventory Report for Ohio, March 2008, compiled by Scott Kirk Ohio Department of Natural Resources, Division of Water Technical Report.

Pavey, Richard, Dennis N. Hull, C. Scott Brockman, Gregory A. Schumacher, David A. Stith, E. Mac Swinford, Terry L. Sole, Kim E. Vorbau, Kevin Kallini, Emily E. Evans, Ernie R. Slucher, and Robert G. VanHorn, 2007, Known and Probable Karst in Ohio, Ohio Department of Natural Resources, Division of Geological Survey Map EG-1.

Powers, D.M. and Swinford, E.M., 2004, Shaded Drift Thickness of Ohio: Ohio Department of Natural Resources, Division of Geological Survey Map GS-3.

Ruedisili, L.C., G.E. Kihn, and R.C. Bell, 1990, Geology of Seneca Caverns, Seneca County, Ohio, Ohio Journal of Science 90(4):106-111.

Slucher, E.R., E.M. Swinford, G.E. Larsen, G.A. Schumacher, D.L. Shrake, C.L. Rice, M.R. Caudill, and R.G. Rea, 2006, Bedrock Geologic Map of Ohio, Ohio Department of Natural Resources, Division of Geological Survey Map BG-1.

Walker, Alfred C., 1986, Ground Water Resources of Erie County, Ohio Department of Natural Resources, Division of Water, map.

APPENDIX A

Block diagrams showing the typical progression of karst geology.

Graphics used with permission from the Columbus Dispatch. Slightly modified.

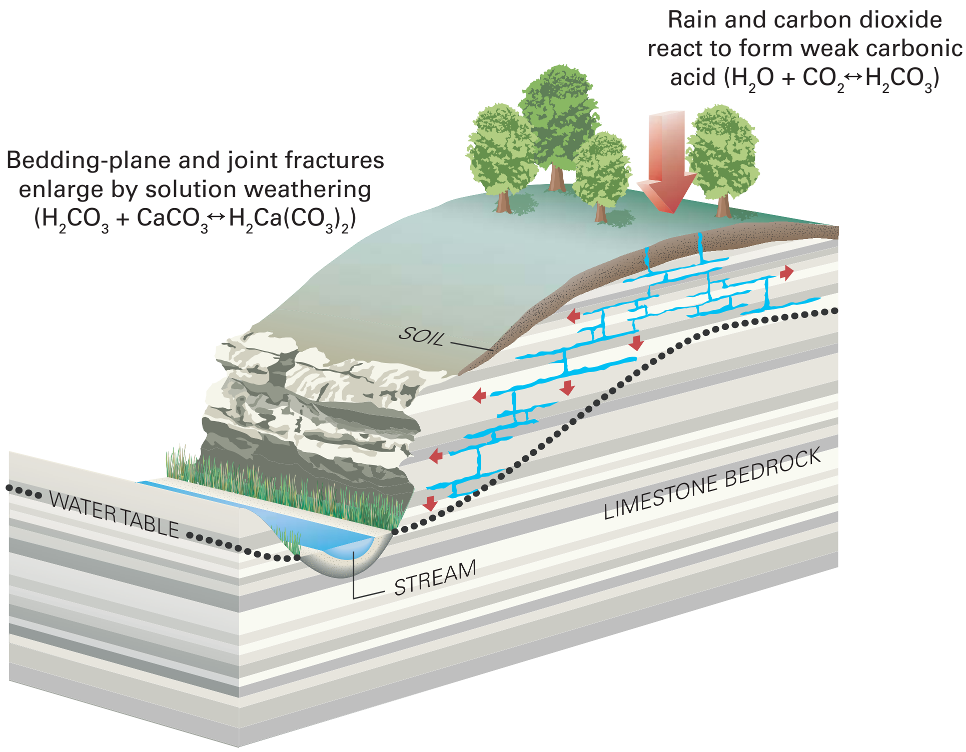

Figure A-1.—Rainwater falling through the air reacts with atmoshperic carbon dioxide to form carbonic acid ($H_2O + CO_2 \Leftrightarrow H_2CO_3$). Upon entering the soil, rainwater reacts with carbon dioxide released from decaying vegetation to form additional carbonic acid. As part of the ground-water environment, carbonic-acid-charged water continues to move downward under the force of gravity into underlying limestone bedrock. The water moves laterally along horizontal fractures (bedding planes) and downward along vertical fractures (joints) until it reaches a depth where all fractures and pore spaces within the rock are filled with water (the water table). As the water moves along fractures, both above and below the water table, small amounts of limestone are dissolved by carbonic acid ($H_2CO_3 + CaCO_3 \Leftrightarrow H_2Ca(CO_3)_2$). Additional limestone is mechanically abraded and removed by the movement of the water.

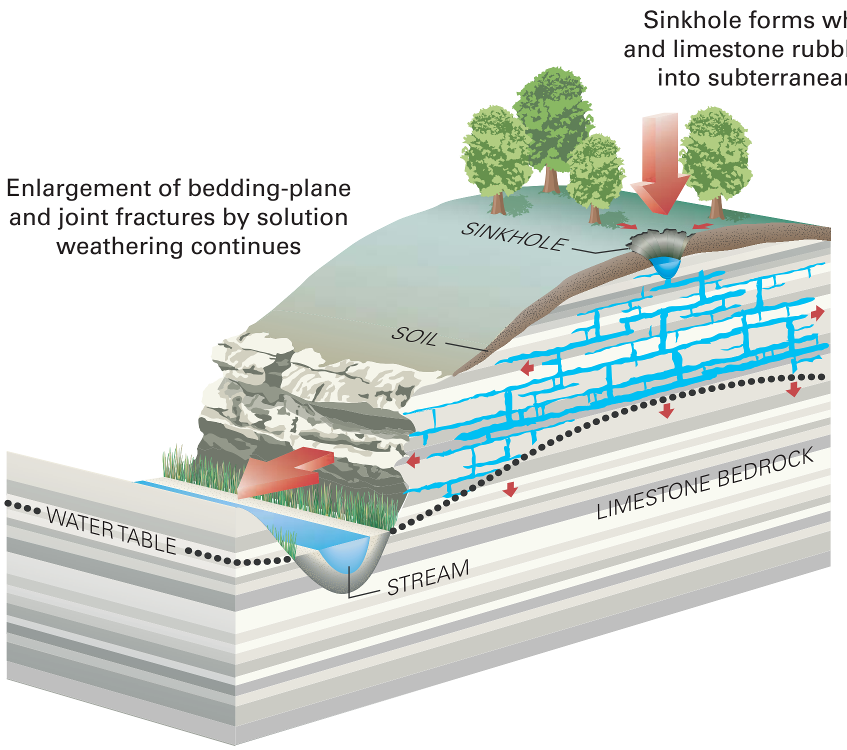

Figure A-2.—With the passing of time, bedrock fractures become greatly enlarged by the dissolution and abrasion process. Sinkholes (dolines) begin to form on the surface where enlarged vertical fractures allow soil and rock debris to collapse into the earth. Surface drainage is diverted directly into the ground-water environment where sinkholes intersect drainageways, thereby accelerating the rate of fracture enlargement through mechanical abrasion. The water table is lowered as ground water escapes to the surface through springs. The terrain created by the presence of numerous sinkholes and other solution features is called karst.

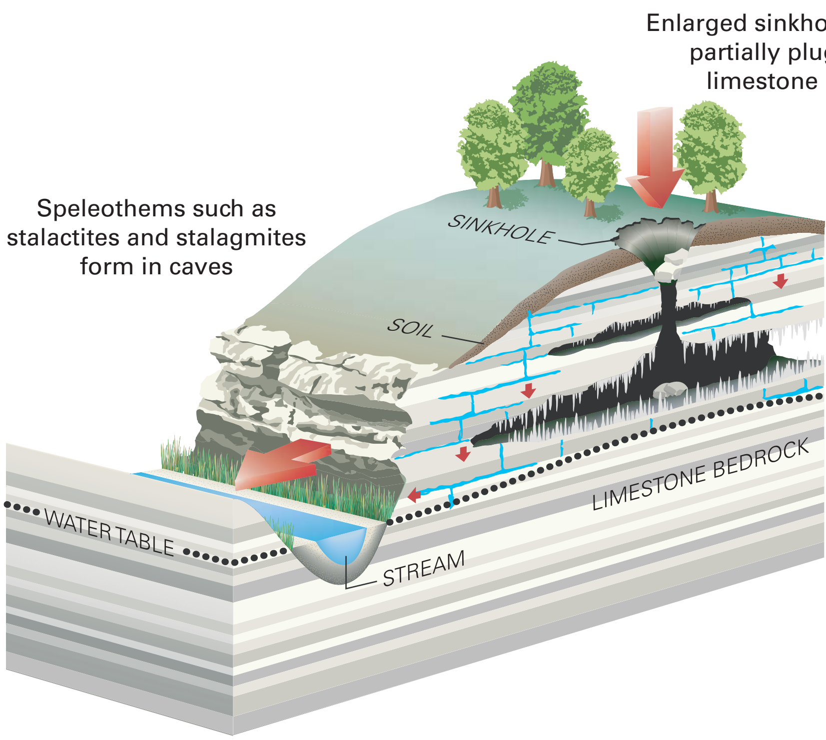

Figure A-3.—Over the course of many centuries, sinkholes continue to enlarge and coalesce with other sinkholes as underground voids collapse and ongoing abrasion and/or dissolution continue to remove bedrock. Horizontal and vertical fractures become enlarged to the extent that they can be classified as a cave (an underground passage large enough for a person to enter). The water table continues to drop in elevation as internal drainage networks within the cave system become more integrated and efficient in collecting and discharging ground water. Ground water saturated with calcium carbonate (calcite) and dripping from cave ceilings and walls or flowing along the cave floor evaporates, causing calcite to be deposited as cave formations (speleothems) such as stalactites, stalagmites, flowstone, and travertine.

APPENDIX B

Frequently asked questions concerning the Bellevue area ground water flooding
Answered by the Ohio Department of Natural Resources—Division of Water

Q: Why did the flooding occur in the Bellevue area?

A: The North Central Region of Ohio, which includes the Bellevue area, reported total precipitation from 10/1/07 through 3/31/08 at 23.55 inches. This record amount of precipitation for this 6-month period is 1.99 inches greater than the previous record of 21.56 inches set in 1898. It was the third wettest March in this region over the past 126 years. The fact that excessive amounts of precipitation fell over the fractured limestone bedrock caused the water table in the limestone aquifer to rise more than 40 feet above normal levels. This would be analogous to quickly dumping 100 gallons of water into a bathtub with the drain open. Water will be leaving the bathtub, but because of the quick influx of water, there will be water standing in the tub until the water can drain out. Flow through the fractures and caverns in the limestone can not keep pace with the influx of water during large storm events.

The ODNR-Division of Water has been in the process of mapping the potentiometric surface within the aquifers in Ohio. These maps show the direction of ground water flow. Using these maps the ground water capture zone for the flooded areas in York and Groton Townships was determined to be approximately 57,000 acres in size. This area encompasses most of Thompson Township and portions of Reed, York, Lyme and Groton Townships. Most of this area, especially Thompson and York Townships have minimal surface drainage because of the high concentration of sinkholes. Ground water recharge is almost instantaneous in these areas as surface water enters the sinkholes. Assuming 30% of the precipitation that falls within the capture zone drains into the sinkholes and thus the aquifer, of the 5.41 inches that fell during March 2008, approximately 2.5 billion gallons recharged the aquifer

Q: How fast does the ground water level fluctuate?

A: That depends on the rate and amount of precipitation in the watershed. During a ground water study in 1992, observed ground water levels in Thompson Township had risen 27 feet in four days in response to receiving less than 3 inches of rain. After 17 days, the water table had only declined 14 feet. Another storm later that same year dropped approximately 5 inches of rain over a six-day period. Ground water levels increased almost 50 feet in three days. After one month of intermittent rains, the ground water level was still 30 feet higher than before the initial 5-inch rainfall event. Assuming the same rate of decline, it would take approximately 70 days to return to pre-storm level if little to no precipitation occurred.

During the 2008 flooding event, ground water levels declined on average 3-4 inches per day. As of October 2008, ground water levels had declined 45-50 feet since March 2008.

Q: Will the ground water flooding happen again?

A: Most likely. Unlike most flooding events caused by surface water run-off, the flooding that occurred in and north of Bellevue was caused by excessive ground water upwelling through near-surface openings in the underlying limestone bedrock. Although this phenomenon is common to the north of this area as represented by the perpetual flow from the “blue holes”, flooding in the area in close proximity to Bellevue has happened only six times since 1800. The last two occurrences were in 1969 and 1937. All three of these occasions were in response to heavy precipitation events. It cannot be ruled out that heavy precipitation events will not occur in the Bellevue area in the future so there is the chance that flooding will occur.

Q: Has the flow in the aquifer been blocked?

A: No. However, the number of sinkholes and the pathways for ground water movement change over time. During the Thompson Township dye trace study in the early to mid 1990’s, Division of Water personnel observed at least 20 new sinkholes form. Existing sinkholes were drastically modified by erosion. It is estimated that sinkholes that do not have grassed buffers and waterways leading to them accept hundreds of tons of sediment each year. This sediment could temporarily block ground water pathways. The hydraulic pressure will build up in the aquifer until a new pathway is opened up or the obstruction is blown out. Division of Water personnel measured ground water levels on two occasions in the area of ground water flooding. The area that experienced the severest flooding from March to June, 2008 showed the greatest decline in ground water levels from September to October, 2008. This indicates that the aquifer is not plugged.

Q: Would ditch maintenance prevent future ground water flooding that was experienced during the spring and summer 2008?

A: No. However, creating and maintaining grassed buffer strips and waterways will reduce the amount of sediment flowing into the sinkholes, which could help surface drainage. Maintaining the ditches could help prevent sinkhole clogging. The large amount of precipitation that fell in March, in combination with the above-normal precipitation during the preceding four months, resulted in millions of gallons of water recharging the aquifer. This caused the ground water levels to rise above land surface in some lower lying areas.

APPENDIX C

A draft, page-size version of the Division of Geological Survey's map, EG-5, Bellevue Flood 2008, by Richard R. Pavey and Donovan M. Powers. Currently under preparation and review.